

The above order of observations facilitates the assessment of the morphological and optical properties in a logical sequence. Adjust the microscope to give Köhler illumination, centre the stage, and insert the polarizer (usually adjusted to the east–west orientation below the condenser. Under these conditions, observe the morphology and colour of the selected fibre. Rotate the stage and observe whether the fibres are pleochroic. Insert the analyser to give crossed polars, and rotate the stage to observe birefringence and whether the extinction angle is parallel to the length of the fibre or oblique. With the polars still crossed, insert the 530 nm retardation plate and rotate the stage to determine the sign of elongation. Finally, examine the fibre under dispersion staining conditions to assess the refractive indices for parallel and normal vibration directions. This may be achieved by observing the dispersion colours at the interface between the fibre and the RI liquid. Withdraw the analyser and the 530 nm retardation plate, increase the illumination, and insert a dispersion staining objective with a central stop in the back focal plane. Adjust the condenser aperture until the field of view becomes dark. View the back focal plane of the objective using either a Bertrand lens or a telescope ocular, and adjust the condenser alignment until the central beam is obscured by the central stop of the lens.

For fibres that exhibit parallel extinction, record the dispersion staining colours with the fibre parallel to the polarizer vibration direction and normal to the polarizer direction. If fibres exhibit oblique extinction, it is necessary to search for fibres that exhibit the maximum extinction angle. This can be achieved either by scanning the slide for such a fibre or by rotating fibres about their axes by touching the top of the cover slip with a needle. It is only in this orientation that a monoclinic fibre exhibits the γ and the α refractive indices. When such a fibre has been located, record the dispersion staining colours with the fibre at both extinction positions.

In practice, any other sequence may be used provided that all of the required properties are observed. For example, if it is difficult to locate any suspected asbestos fibres on the prepared mount because the sample is dominated by non-asbestos fibres, or if a random sample is being searched, the sample should be scanned with the microscope in the crossed polars condition to detect the asbestos fibres. The sign of elongation may also be observed by interpretation of the observed dispersion staining colours.

The observations made of the morphology and the optical properties of the fibre are recorded. Identification is based on comparing the recorded observations on the fibres selected for analysis (and mounted in the appropriate RI liquid) against the properties of asbestos reference standards. The compositions and optical properties of commercial chrysotile, amosite and crocidolite do not vary significantly, and therefore a close match between the optical properties of the sample fibre and the asbestos standard is normally achieved. Further representative fibres will need to be examined if the observations are inconclusive, or if more than one type of fibre was found in the stereomicroscopic or PLM analysis. For tremolite, actinolite and anthophyllite, the iron mass fraction can vary significantly from one source to another; higher iron mass fractions result in higher refractive indices. Examples of this variability can be seen by comparing the tremolite, actinolite and anthophyllite samples from the SRM 1867 and HSE sets of reference standards, as illustrated in Annex D.

7.2.3.7 Identification of asbestos

7.2.3.7.1 Morphology

A detailed description for the morphology that is characteristic of asbestos is as follows. This morphology is characteristic of the larger fibres seen in stereomicroscope examinations and of fibres selected from laboratory samples for PLM identification of fibre type.

In the light microscope, the asbestiform habit is generally recognized by the following characteristics:

- a) the presence of fibre aspect ratios in the range of 20:1 or higher for fibres longer than 5 μm ;
- b) the capability of longitudinal splitting into very thin fibrils, generally less than 0,5 μm in width;
- c) in addition, observation of any of the following characteristics for the fibre type under consideration provides additional confirmation that the fibres are asbestiform:
 - 1) parallel fibres occurring in bundles,
 - 2) fibre bundles displaying splayed ends,
 - 3) fibres in the form of thin needles,

- 4) matted masses of individual fibres,
- 5) fibres showing curvature.

In practice, if chrysotile, crocidolite or amosite is identified in a commercial product, the assumption can safely be made that the fibres are asbestiform and that these fibres conform to the description above. This assumption can be made because these three types of asbestos were mined and processed to yield fibres with specific properties for intentional incorporation into products. Some anthophyllite asbestos was used in a few commercial products, but very little was mined and used commercially. Tremolite asbestos has been found in some surfacing and fireproofing applications in Japan. However, other than these occurrences, the amphiboles tremolite, actinolite, and richterite/winchite were not generally used in commerce, and their presence in a product is more likely a consequence of naturally occurring contamination of one or more of the major constituents. Accordingly, no assumption can be made as to whether the amphibole is asbestiform or non-asbestiform. Anthophyllite can occur as contamination of other mineral products, and in such situations no assumption can be made as to whether it is asbestiform or non-asbestiform. In some samples, these amphiboles may exhibit a mixture of morphological types, and quantitative determination of the regulatory status of such samples may require a detailed study of the fibre size distribution that is beyond the scope of this part of ISO 22262.

In general, for this part of ISO 22262, the presence of either the asbestiform or the non-asbestiform analogues of tremolite, actinolite, anthophyllite or richterite/winchite can usually be specified. If the majority of the amphibole fibres longer than 5 µm have aspect ratios equal to or lower than 5:1, and if the fibres do not exhibit any of the characteristics in c), it can be concluded that the amphibole is probably non-asbestiform, with the degree of certainty increasing with decreasing maximum aspect ratio. If any amphibole fibres longer than 5 µm with aspect ratios in the range of 20:1 or higher are observed, then it can be concluded that amphibole asbestos is probably present, with the degree of certainty increasing with increasing aspect ratio.

NOTE This is intended as guidance for analysts to discriminate between non-asbestiform and asbestiform amphibole populations. It is not intended to override the definition of asbestos as presented in 2.9 nor to override any national regulation.

It is necessary to appreciate that some samples may still present ambiguities with respect to discrimination between asbestiform and non-asbestiform analogues, and such ambiguities, when observed, shall be reported as part of the results.

7.2.3.7.2 Colour and pleochroism

Colour and pleochroism are observed using plane polarized light. Pleochroism is a diagnostic property in the identification of crocidolite. Crocidolite has a strong absorption, which gives a dark blue colour when the fibres are parallel to the polarizer vibration direction, changing to pale blue or grey when the fibres are perpendicular to the polarizer vibration direction. This is illustrated in Figures D.13 and D.14. Pleochroism in amosite may occur after heating, or occasionally in unheated fibres, depending on the Fe/Mg mass fraction ratio of the mineral. Chrysotile shows little colour contrast and no pleochroism in plane polarized light. Depending on the iron mass fraction, actinolite may exhibit a green colour when the fibres are parallel to the polarizer vibration direction, changing to a grey or yellowish colour when the fibres are perpendicular to the polarizer direction. Pleochroism in the HSE actinolite reference sample is illustrated in Figures D.43 and D.44.

7.2.3.7.3 Birefringence

When a particle with more than one RI is observed between crossed polars with its planes of vibration at 45° to those of the polarizer, interference colours are observed against the dark background. For asbestos, these interference colours depend on the fibre thickness, the birefringence and on the degree of randomness of the fibril orientation about the fibre axis.

Between crossed polars, an asbestos fibre aligned at 45° to the polarizer vibration direction should be clearly visible. Chrysotile has a low birefringence and gives a grey colour for thin fibres, and a white colour or higher first (or even second) order colours for thick fibres. Crocidolite has a low birefringence and anomalous interference colours caused by strong absorption in the visible light range. Amosite has moderate birefringence, giving white interference colours for thin fibres and higher first or second order colours for thick fibres. Tremolite, actinolite and anthophyllite, and richterite/winchite similarly exhibit moderate birefringence. Fibres with a variable thickness, e.g. with wedge-shaped cross-sections, show parallel bands of colour along their lengths, representing lower interference colours for progressively thinner sections. Examples are shown in Annex D.

Isotropic materials have zero birefringence, and therefore do not exhibit interference colours. Between crossed polars, isotropic materials such as man-made vitreous fibres are almost invisible, but, depending on the difference between their RI and that of the immersion liquid, are often seen easily with the 530 nm retardation plate in position or with slightly uncrossed polars. Interference colours can be used to distinguish asbestos from some natural organic fibres, which may show non-uniform interference along the fibre length and also incomplete extinction.

7.2.3.7.4 Extinction angle

As the microscope stage is rotated through 360°, an asbestos fibre viewed between crossed polars disappears from view or “extinguishes” at four positions, each 90° apart, while at an angle of 45° to an extinction position, interference colours should be visible. Many fibres, including asbestos, generally show complete extinction when parallel to the vibration directions of the polarizer or the analyser. Chrysotile, amosite, crocidolite and anthophyllite each show parallel extinction when the fibre is parallel to the vibration direction of the polarizer or analyser. Tremolite, actinolite, and richterite/winchite may exhibit parallel extinction or oblique extinction, depending on the orientation of the fibre and the crystalline nature of the fibre. Highly asbestiform fibres of these amphiboles may show parallel extinction at all axial orientations. Other fibres of high aspect ratio may show oblique extinction, and axial rotation of the fibre by touching the cover glass of the slide with a needle allows the maximum extinction angle to be determined. Tremolite and some low-iron actinolite fibres that exhibit only parallel extinction cannot easily be discriminated from anthophyllite. However, it is unlikely that *all* of the tremolite or actinolite fibres in a sample would exhibit parallel extinction, and observation of some with oblique extinction angles would confirm the identity of the mineral, with the presumption that parallel extinction fibres with otherwise similar properties are the same mineral species. In these cases, reliable discrimination between anthophyllite and either tremolite or actinolite may only be possible by examination of the compositions of the fibres by SEM or TEM.

7.2.3.7.5 Sign of elongation

The sign of elongation describes the relationship between the length of the fibre and the optical properties. For asbestos fibres the two available vibration directions are parallel to the long axis and perpendicular to it. If the high RI vibration direction is parallel to the long axis, then the fibre is described as positive; if the low RI vibration direction is parallel to the long axis, the fibre is described as negative. Between crossed polars, with the 530 nm retardation plate inserted at 45° to the polarizer and analyser vibration directions, the sign of elongation can be determined by observing the colours of fibres that previously had given grey or white first order interference colours between crossed polars. For a retardation plate with the slow direction (usually marked) in the northeast–southwest direction, the first order colours observed are as follows:

Positive fibre	blue–green with fibre northeast–southwest
	orange–yellow with fibre northwest–southeast
Negative fibre	orange–yellow with fibre northeast–southwest
	blue–green with fibre northwest–southeast

Crocidolite is the *only* asbestos type that has a negative sign of elongation. However, exposure to temperatures of about 300 °C or higher may result in a reversal of the sign of elongation of crocidolite to positive. In such cases, however, the thermal history of the fibre is usually indicated by a change of colour.

7.2.3.7.6 Refractive indices

The refractive indices of an asbestos fibre are assessed by mounting a clean separated fibre in a liquid of known RI and orienting it either parallel or perpendicular to the polarizer vibration direction. One or more observations are conducted to determine whether the RI of the fibre is higher than, lower than or equal to that of the immersion liquid.

NOTE Classical mineralogical methods (References [16]–[18]) can be used for determination of refractive indices, but use of these methods requires access to a more extensive range of RI liquids than is specified in this part of ISO 22262, and it is also necessary to prepare multiple slide mounts in order to measure the γ and α indices for asbestos fibres.

Remove all filters from the light path except the daylight colour correction filter and the polarizer. Use the central stop dispersion staining objective to view fibres mounted in a liquid with an RI close to that of the fibre, so that dispersion staining colours can be observed. When dealing with an unknown sample, the observations a) to e) listed in the following can be used to help choose a suitable RI liquid such that the RI of the fibre and the liquid are sufficiently close that dispersion staining colours are produced.

Differences in dispersion between particles and liquids mean that, even though the refractive indices match at one wavelength, they may be quite different at others. This leads to colour effects at the particle/liquid interface when fibres are observed in matching RI liquids using white light. In practice, it is easiest to observe small bright particles and colours against a black background; these conditions are achieved with a central stop in the back focal plane of the objective when used with an axial beam of light produced by the condenser iris. The colours observed at the particle/liquid interface depend on the precise wavelength at which the RI of the liquid and that of the fibres match. When the match of RI is at a wavelength of 589,3 nm (the D line of sodium), the colour at the particle/liquid interface is a deep blue–magenta. For central stop dispersion staining, the colour observed indicates how close, and in which direction, the RI of the particle differs from that of the immersion medium:

- | | | | | |
|----|------------------------|----|--------------------------|--------------------------|
| a) | Fibre refractive index | >> | Liquid refractive index: | White |
| b) | Fibre refractive index | > | Liquid refractive index: | Purple–red/orange/yellow |
| c) | Fibre refractive index | = | Liquid refractive index: | Deep blue–magenta |
| d) | Fibre refractive index | < | Liquid refractive index: | Blue/blue–green |
| e) | Fibre refractive index | << | Liquid refractive index: | White |

Different colours are observed when the fibre is oriented parallel or perpendicular to the polarizer vibration direction, arising from the different refractive indices of asbestos fibres in the two perpendicular directions relative to the polarizer vibration direction. A recording of the predominant colours is used to characterize the refractive indices of the fibres. Identification of chrysotile, amosite and crocidolite can be performed with a dispersion staining objective using three high dispersion liquids having the RI values 1,550 for chrysotile, 1,680 for amosite, and 1,700 for crocidolite. In practice, for commercial chrysotile, because of variations in the fibre composition according to the source, a small range of fibre refractive indices and dispersion staining colours may be encountered. The refractive indices of commercial amosite and crocidolite do not vary significantly. For the purpose of this part of ISO 22262, the three RI liquids adequately cover the observed range of refractive indices for chrysotile, amosite, and crocidolite from all known major commercial sources. Crocidolite from Bolivia is an exception in that the refractive indices are lower than those from other sources of crocidolite. However, Bolivian crocidolite is very rare in commerce. Should Bolivian crocidolite be encountered, it can be readily recognized on the basis of its fibrous morphology, negative sign of elongation, and blue–grey pleochroism.

Identification of tremolite, actinolite and anthophyllite can often be performed using a dispersion staining objective using liquids of RI values 1,605 and 1,630. Tremolite or actinolite should be suspected if some of the fibres exhibit oblique extinction, and the γ index observed parallel to the extinction position can be used to define whether the fibre is tremolite or actinolite. If it is important to discriminate between tremolite and actinolite, classify fibres as tremolite if the γ index is estimated to be equal to or lower than 1,637 and as actinolite if the γ index is estimated to be higher than 1,637.

Some sources of talc contain fibres that can be mistaken for anthophyllite. These fibres have intergrowths of both the anthophyllite and talc crystal structures. The fibres exhibit refractive indices that are lower than those of anthophyllite and intermediate between those of talc and anthophyllite. If this type of fibre is present, examine the sample in a liquid of RI 1,615. If no γ indices are observed that are higher than 1,615, classify the fibres as talc. Classify any fibres with γ indices equal to or exceeding 1,615 as anthophyllite.

Identification of richterite/winchite asbestos is difficult by PLM alone. Richterite/winchite should be suspected if the sample also contains vermiculite or talc. Attempts to identify richterite/winchite by PLM alone usually result in classification of the fibres as actinolite, and such an error may be important for regulatory interpretation. Where richterite/winchite is suspected, and the fibres exhibit properties similar to those of actinolite, it is recommended that the fibres be identified by either SEM or TEM.

Annex C shows dispersion staining charts for the α and γ refractive indices of chrysotile, amosite, crocidolite, tremolite, actinolite, anthophyllite, and richterite/winchite in the appropriate RI liquids. Chrysotile exhibits a

small range of refractive indices, depending on the source. For each of the types of asbestos, an acceptable range of colour for the α and γ dispersion staining colours is indicated, representing the observed range in minerals from commercial sources. For chrysotile, it is also important to establish that the λ_o values for the parallel and normal orientations with respect to the polarizer vibration direction do not differ by more than 100 nm in recognition of its low birefringence. For chrysotile, although there is a range of refractive indices depending on the source, studies have shown that the two indices vary in an approximately parallel manner.

Figures D.1 and D.2 show an example of chrysotile, mounted in 1,550 RI liquid, viewed between crossed polars with the 530 nm retardation plate inserted. Note the fibrillar, wavy appearance, and the blue–green colour in the northeast direction, changing to an orange colour when the fibres are rotated into the northwest direction, showing that the fibres have a positive sign of elongation. Figures D.3 and D.4 show an example of chrysotile viewed under dispersion staining conditions, showing magenta for fibres parallel to the vibration direction of the polarizer and blue for fibres normal to the vibration direction of the polarizer. However, it is necessary to consider that the colours exhibited in the two directions vary depending on the source of the chrysotile and any prior heating or acid treatment. Nevertheless, any variation applies to both the α and γ refractive indices, and the difference between the two (birefringence) remains nearly constant regardless of the source of the chrysotile.

Figures D.5 and D.6 show an example of amosite, mounted in 1,680 RI liquid, viewed between crossed polars with the 530 nm retardation plate inserted. The thin fibres exhibit a blue–green colour in the northeast direction, changing to an orange colour when the fibres are rotated into the northwest direction, showing that the fibres have a positive sign of elongation. Because of the higher birefringence of amosite, some of the thicker fibres exhibit first and second order interference colours that can be compared with the interference colour chart in Annex B. Figures D.7 and D.8 show amosite viewed under dispersion staining conditions, with a gold colour for fibres parallel to the vibration direction of the polarizer and blue for fibres normal to the vibration direction of the polarizer. Except for heated amosite, these colours vary only slightly for amosite from different sources. The behaviour of heated amosite for the two fibre orientations is illustrated in Figures D.9 and D.10. Heated amosite exhibits significantly higher refractive indices, and dark brown–light brown pleochroism for fibres parallel and normal to the polarizer vibration directions, respectively.

Figures D.11 and D.12 show an example of crocidolite, mounted in 1,700 RI liquid, viewed between crossed polars with the 530 nm retardation plate inserted. The fibres exhibit a yellow–orange colour in the northeast direction, changing to a blue colour when the fibres are rotated into the northwest direction, showing that the fibres have a negative sign of elongation. The birefringence of crocidolite is very low, so the dispersion staining colours for fibres parallel and normal to the polarizer vibration direction are not very different. However, a lighter blue is discernable for the parallel direction, indicating that the lower RI is parallel to the length of the fibre (Figures D.13 and D.14). The blue–grey pleochroism of crocidolite is shown in Figures D.15 and D.16. The behaviour of heated crocidolite for the two fibre orientations is illustrated in Figures D.17 and D.18. Heated crocidolite exhibits dark brown–light brown pleochroism for fibres parallel and normal to the polarizer vibration directions, respectively. For heated crocidolite such as that illustrated, the sign of elongation is positive, and in this condition electron microscopy with energy dispersive X-ray analysis is necessary to discriminate between crocidolite and amosite.

Figures D.19 and D.20 show an example of SRM 1867 tremolite, mounted in 1,605 RI liquid, viewed between crossed polars with the 530 nm retardation plate inserted. The thin fibres exhibit a blue–green colour in the northeast direction, changing to an orange colour when the fibres are rotated into the northwest direction, showing that the fibres have a positive sign of elongation. Because of the moderate birefringence of tremolite, some of the thicker fibres can exhibit first and second order interference colours that can be compared with the interference colour chart in Annex B. Figures D.21 and D.22 show SRM 1867 tremolite viewed under dispersion staining conditions, with a yellow colour for fibres parallel to the extinction position closest to the vibration direction of the polarizer and dark blue for fibres at the other extinction position. The dark blue colour of the fibre in Figure D.22 and the magnitude of the extinction angle indicate that this fibre presents the α RI at this orientation. Figures D.23 to D.26 show SRM 1867 tremolite mounted in 1,625 RI liquid, which is intermediate between the γ and α indices of the fibres. Figures D.35 to D.38 show an example of HSE reference tremolite, mounted in 1,605 RI liquid. This variety of tremolite exhibits parallel extinction.

Figures D.27 and D.28 show an example of SRM 1867 actinolite, mounted in 1,630 RI index liquid, viewed between crossed polars with the 530 nm retardation plate inserted. The thin fibres exhibit a blue–green colour in the northeast direction, changing to an orange colour when the fibres are rotated into the northwest direction, showing that the fibres have a positive sign of elongation. Because of the moderate birefringence of tremolite, some of the thicker fibres can exhibit first and second order interference colours that can be compared with the

interference colour chart in Annex B. Figures D.29 and D.30 show SRM 1867 tremolite viewed under dispersion staining conditions, with a purple–red colour for fibres parallel to the extinction position closest to the vibration direction of the polarizer and light blue for fibres at the other extinction position. Figures D.39 to D.44 show an example of HSE reference actinolite mounted in 1,640 RI liquid. The HSE actinolite is considerably more asbestiform than the SRM 1867 actinolite, and exhibits parallel extinction as well as pleochroism as illustrated in Figures D.43 and D.44.

Figures D.31 and D.32 show an example of SRM 1867 anthophyllite, mounted in 1,605 RI liquid, viewed between crossed polars with the 530 nm retardation plate inserted. The thin fibres exhibit a blue–green colour in the northeast direction, changing to an orange colour when the fibres are rotated into the northwest direction, showing that the fibres have a positive sign of elongation. Because of the moderate birefringence of anthophyllite, some of the thicker fibres can exhibit first and second order interference colours that can be compared with the interference colour chart in Annex B. Figures D.33 and D.34 show anthophyllite viewed under dispersion staining conditions, with blue–purple colours for fibres parallel to the vibration direction of the polarizer and light blue for fibres normal to the vibration direction of the polarizer. Figure D.33 shows some fibres that exhibit purple dispersion staining colours. This indicates that the RI in that orientation is higher than 1,630, representing the γ index. Other fibres exhibit a blue colour, which indicates that the RI in the particular axial orientation is lower than 1,630. This is probably a result of intergrowths of talc in the fibre bundle, since all fibres in this orientation relative to the polarizer direction should exhibit only the γ index. Figures D.45 to D.48 show an example of HSE reference anthophyllite in 1,605 RI liquid.

Figures D.49 and D.50 show an example of richterite/winchite, mounted in 1,630 RI liquid, viewed between crossed polars with the 530 nm retardation plate inserted. The thin fibres exhibit a blue–green colour in the northeast direction, changing to an orange colour when the fibres are rotated into the northwest direction, showing that the fibres have a positive sign of elongation. Because of the moderate birefringence, some of the thicker fibres exhibit first and second order interference colours that can be compared with the interference colour chart in Annex B. Figures D.51 and D.52 show richterite/winchite viewed under dispersion staining conditions, with a purple colour for fibres parallel to the extinction position closest to the vibration direction of the polarizer and blue for fibres at the other extinction position. Regardless of the highly asbestiform appearance of this sample, the fibres exhibit oblique extinction.

7.2.4 Interferences

7.2.4.1 Heated asbestos

Changes occur to asbestos when it is heated. Therefore, care should be taken if sample preparation involves heating the asbestos-containing material. Even short exposure of crocidolite to temperatures of 300 °C to 500 °C may cause colour changes, and increases in both RI and the birefringence. For crocidolite, the changes with heating are: the sign of elongation reverses and the colour changes from grey to yellow then orange–brown; pleochroism is suppressed at the grey coloration stage, but reappears on further heating. For amosite, the sign of elongation remains positive, but the colour changes from yellow to a dark brown, and pleochroism is observed. Thus, heat-degraded crocidolite and amosite cannot be distinguished from each other by light microscopy after exposure to temperatures above about 500 °C. The refractive indices of chrysotile increase after significant exposure to temperatures of about 600 °C or greater: the birefringence decreases and, in a few cases, the sign of elongation changes to negative and the fibres become pale brown. The alteration of asbestos by heat is dependent on both the duration and the temperature of exposure. Prolonged exposure to high temperatures can result in complete degradation, but, with judicious sampling, unaffected fibres can often be detected in peripheral locations or in debris that became detached during installation. However, in extreme situations, analytical electron microscopy may be required to aid identification. Examples of heated amosite and crocidolite in plane polarized light are shown in Annex D.

7.2.4.2 Leached chrysotile

Exposure of chrysotile to acidic aqueous media may result in reduction of the refractive indices as a consequence of leaching of magnesium from the crystal structure. Progressive leaching also results in reduction of the birefringence, and ultimately the fibre becomes isotropic. In addition to the action of mineral acids used in some of the procedures in this part of ISO 22262, leaching may also occur in chrysotile exposed to aggressive water (water with only low mass fractions of dissolved calcium and magnesium, and with low pH values). Leached

chrysotile may be encountered on the surfaces of chrysotile cement products such as roofing materials after long periods of exposure to rain.

7.2.4.3 Fibres with morphological and/or optical properties similar to those of asbestos

Most of the fibres discussed in the following paragraphs occur infrequently in samples presented for analysis. However, analysts need to be aware of their existence and distinguishing characteristics in PLM. There are five types of fibre that can resemble chrysotile. Some mineral fibres can also superficially resemble amphiboles.

Polyethylene is the most important of the interfering fibres because it is used as an asbestos substitute. Shredded polyethylene resembles chrysotile. In 1,550 RI liquid, the dispersion staining colours are within the range for those of chrysotile, although experienced analysts will observe morphological differences and de-saturation of the blue colour perpendicular to the fibres because of the low RI in this direction. The birefringence is also higher than that of chrysotile. If polyethylene is suspected, the melting of fibres on a hot plate or in a flame will readily distinguish them from chrysotile.

Fibres from leather have low birefringence and similar dispersion staining colours to chrysotile. At magnifications below 100 times, they appear to have similar morphology to that of chrysotile, but they usually exhibit clearly visible uniform fibrils. Individual chrysotile fibrils are too small to be seen by PLM, although uniform bundles of fibrils are visible. In most instances, the differences between chrysotile and leather can be detected during stereomicroscope examination. If leather is suspected to be present, the sample may be ashed at 400 °C to remove it, and then the residual ash can be reexamined for identification of asbestos. Care should be taken not to allow the sample temperature to rise above 500 °C.

Macerated aramid fibres may appear to have a morphology similar to that of chrysotile, but these fibres can be recognized by their extremely high birefringence showing high-order white interference colours. When mounted in 1,550 RI liquid, the refractive indices are clearly inconsistent with those of chrysotile.

Spider web and natural organic fibres such as cellulose and feathers have refractive indices close to those of chrysotile and show similar interference colours between crossed polars. In a sample with little non-fibrous material, the morphology of these fibres can be readily distinguished from that of chrysotile. However, in samples containing significant particulate material, sometimes only a small portion of the fibre can be observed due to obscuration by the particles and this can lead to misidentification. These fibres can be removed by ashing the sample or exposing individual fibres to a flame.

Talc fibres are thin ribbons that may sometimes be recognized by characteristic morphological twists. For the RI parallel to the fibre length, they have a value in the range 1,589 to 1,600, resulting in a pale yellow dispersion staining colour when immersed in 1,550 RI liquid. The other two refractive indices of talc are in the ranges 1,539 to 1,550 and 1,589 to 1,600, and with a dispersion staining objective, blue and pale yellow colours perpendicular to the fibre are observed in 1,550 RI liquid at different orientations as the fibre is "rolled". It is important to demonstrate that the γ index of any straight fibres that do not exhibit ribbon-like morphology is lower than 1,615, in order to exclude the possibility that the fibres are anthophyllite

Fibrous brucite normally consists of straight white to pale brown fibres, but brucite lacks the tensile strength of asbestos. It is brittle and is soluble in acid. Brucite has a negative sign of elongation, which reverses to positive when heated. Sometimes brucite fibres may appear to be isotropic. It is distinguished from chrysotile by its refractive indices. In central stop dispersion staining, brucite yields colours of yellow to pale yellow in 1,550 RI liquid.

Superficially, fibrous wollastonite can be mistaken for tremolite. Fibrous wollastonite has an acicular morphology, is very brittle, white in appearance, and is slowly soluble in acid. After treatment for a short time (e.g. 15 min) in 100 g/l hydrochloric acid, the fibres exhibit etched areas. Wollastonite always displays a non-zero extinction angle. The RI almost parallel to the fibre is in the range 1,628 to 1,650. The other two refractive indices are in the ranges 1,626 to 1,640, and 1,631 to 1,653, and are observed across the fibre, at different orientations as the fibre is rolled. A distinctive feature is that the RI with the length of the fibre almost parallel to the polarizer vibration direction is intermediate between the two refractive indices observed at the different orientations across the fibre as the fibre is rolled. Examination of many fibres with crossed polars and with the 530 nm retardation plate inserted shows most as having a positive sign of elongation, and fibres in other orientations appear to have a negative sign of elongation. Gentle pressure on the cover slip with a needle can be used to rotate a fibre and show it to change from a positive to a negative sign of elongation as it is rolled into a different axial orientation.

Diatomaceous earth may exhibit acicular fragments with the appearance of fibres. However, these fibres have a low RI of approximately 1,42 and are readily distinguished from asbestos fibres using dispersion staining. Also, there is usually characteristic morphology that can be recognized when the material is examined at magnifications around 500 times.

7.2.4.4 Identification of other sample components

A laboratory conducting routine analysis selectively removes fibres for examination and ignores the majority of the non-asbestos materials. The composition of many asbestos products is relatively uniform during the manufacture and a wider knowledge of these non-asbestos materials can be helpful in recognizing many common products or formulations. Because of this, the analyst should become familiar with the information in Annex A.

8 Analysis by SEM

8.1 General

Complete details relating to identification of mineral fibres, including asbestos fibres, using SEM are given in ISO 14966.^[7]

8.2 Requirements

8.2.1 Scanning electron microscope, with an accelerating voltage of at least 20 kV.

8.2.2 Energy dispersive X-ray system. The SEM shall be equipped with an energy dispersive X-ray analyser capable of achieving a resolution better than 170 eV (FWHM) on the Mn K_{α} peak. The performance of an individual combination of SEM and solid-state X-ray detector is dependent on a number of geometrical factors. The X-ray detector shall be capable of detecting sodium in crocidolite, in order to permit discrimination between crocidolite and amosite.

8.2.3 Vacuum coating unit, capable of producing a vacuum better than 0,013 Pa. It shall be used for vacuum deposition of carbon on the SEM specimens. A sample holder is required which allows the SEM specimens to be continuously rotated and tilted during the coating procedure.

8.3 Calibration

For the purposes of this method, calibration consists of obtaining EDXA spectra from reference samples of chrysotile, amosite, crocidolite, tremolite, actinolite, anthophyllite, and richterite/winchite. The chemical compositions of commercial chrysotile, amosite, crocidolite and anthophyllite do not vary substantially, and comparison of unknown EDXA spectra with those from the three reference asbestos samples constitutes sufficient identification for this part of ISO 22262. For most purposes, it is not necessary to discriminate between tremolite and actinolite, since the compositional boundary between them is a matter of convention. When it is necessary to discriminate between tremolite and actinolite, the SRM 1867 tremolite and actinolite samples are particularly useful, since these samples have compositions just below and just above the boundary defined by the International Mineralogical Association. In some applications, the magnesium may be partially leached from chrysotile, leading to a chemical composition that approaches that of talc. In order to facilitate the discrimination between chrysotile and talc or anthophyllite, it is recommended that an EDXA spectrum also be obtained from a known sample of talc. Use this spectrum to define the upper limit of the magnesium mass fraction in talc. Examples of EDXA spectra obtained on the SRM 1866 and SRM 1867 samples, the HSE reference asbestos samples, Bolivian crocidolite and richterite/winchite are illustrated in Annex E. For positive identification, reference EDXA spectra from asbestos standards similar to those shown in Annex E should be recorded using the specific combination of SEM and EDXA detector, since the geometries and detector efficiencies vary between different instruments.

8.4 Sample preparation

Select representative fibres, either from the original laboratory sample or from the residue remaining after treatment according to the procedures specified in 7.2.2 and 7.2.3. Mount these fibres either directly on a graphite SEM stub or on double-sided adhesive tape on an SEM stub. Place the SEM stub in the vacuum coating unit and evaporate a thin film of carbon on to the surface of the fibres.

8.5 Qualitative analysis by SEM

8.5.1 Acquisition of EDXA spectra

It is important to obtain the EDXA spectrum from clean areas of the fibre, since distortion of peak heights by contributions from attached particles may compromise the identification. Particles adjacent to the fibre under analysis may also contribute to the EDXA spectrum, and this effect should be minimized to the extent possible.

8.5.2 Sample analysis

The SEM stub with the unknown fibres is examined at a low magnification in the SEM, and EDXA spectra are acquired from regions of the fibres that are clear of other attached particles. The EDXA spectra are compared with the reference spectra.

8.5.2.1 Chrysotile

Classify a fibre as chrysotile if:

- a) the Mg and Si peaks are clear, and comparable in Mg/Si peak height ratio with that of the reference;
- b) any Fe, Mn and Al peaks are small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

IMPORTANT — Anthophyllite and talc both yield EDXA spectra that conform to these specifications, but the Mg/Si peak height ratio for these minerals is lower than that for chrysotile. In order to avoid erroneous classification of talc or anthophyllite as chrysotile, take account of the Mg/Si peak height ratio and calibrate the EDXA detector using known samples of chrysotile and talc.

8.5.2.2 Amosite

Classify a fibre as amosite if:

- a) the Mg, Si and Fe peaks are comparable in ratio to those of the reference amosite;
- b) no statistically significant peaks from Na or Al are present;
- c) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

8.5.2.3 Crocidolite

Classify a fibre as crocidolite if:

- a) the Na, Si and Fe peaks are comparable in ratio with those of the reference crocidolite;
- b) any peak from Mg is small, and no peaks from Al or Mn are visible.

NOTE 1 Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

NOTE 2 If a large peak from Mg is present, it is possible that the fibre is magnesio-riebeckite. Bolivian crocidolite is the only known commercial source, although this variety of crocidolite can occur as contamination of other minerals.

8.5.2.4 Tremolite

Classify a fibre as tremolite if:

- a) the Mg, Si, Ca and Fe peaks are comparable in ratio to those of reference tremolite;
- b) no statistically significant peaks from Na or Al are present;
- c) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

8.5.2.5 Actinolite

Classify a fibre as actinolite if:

- a) the Mg, Si and Fe peaks are comparable in ratio to those of the reference actinolite;
- b) no statistically significant peaks from Na or Al are present;
- c) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

8.5.2.6 Anthophyllite

Classify a fibre as anthophyllite if:

- a) the fibre is straight and exhibits no evidence of a ribbon-like structure;
- b) the Mg and Si peaks are comparable in ratio to those of the reference anthophyllite — anthophyllite from some sources may not exhibit a peak from Fe, although in commercial anthophyllite a peak from Fe will probably be observed;
- c) no statistically significant peaks from Na or Al are present;
- d) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

8.5.2.7 Sodic–calcic amphibole asbestos (richterite/winchite)

Classify a fibre as sodic–calcic amphibole if:

- a) the spectrum is similar to that of actinolite or tremolite, but the Ca peak is substantially smaller and an Na peak is present — a K peak may also be evident;
- b) no statistically significant peak from Al is present;
- c) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

9 Analysis by transmission electron microscope

9.1 General

Full details relating to identification of asbestos fibres using TEM are given in ISO 10312^[2] and ISO 13794^[4]. Additional information on the investigation of minerals using TEM is given in References [26]–[29]. A simple technique for quantitative measurement of electron diffraction patterns is available (Reference [30]). Detailed interpretation of single-crystal electron diffraction patterns, sometimes required for definitive identification of amphibole fibres, can be accomplished using a computer program, e.g. XIDENT (Reference [31]).

9.2 Requirements

9.2.1 Transmission electron microscope, operating at an accelerating potential of 80 kV to 120 kV. The TEM shall have an illumination and condenser lens system capable of forming an electron probe smaller than 250 nm in diameter.

9.2.2 Energy dispersive X-ray analyser. The TEM shall be equipped with an energy dispersive X-ray analyser capable of achieving a resolution better than 170 eV (FWHM) on the Mn K_{α} peak. Since the performance of individual combinations of TEM and EDXA equipment is dependent on a number of geometrical factors, the required performance of the combination of the TEM and X-ray analyser is specified in terms of the measured X-ray intensity obtained from a fibre of small diameter, using a known electron beam diameter. Solid-state X-ray detectors are least sensitive in the low-energy region, and so measurement of sodium in crocidolite is the primary performance criterion. The combination of electron microscope and X-ray analyser shall yield, under routine analytical conditions, a peak from sodium that allows discrimination between the spectra from crocidolite and amosite.

9.2.3 Vacuum coating unit. If carbon-coated specimen grids are not available, a vacuum coating unit capable of producing a vacuum better than 0,013 Pa shall be used for vacuum deposition of carbon for preparation of carbon-coated grids.

9.2.4 Calibration grids. TEM specimen grids prepared from dispersions of chrysotile, amosite, crocidolite, tremolite, actinolite, anthophyllite, richterite/winchite, and talc are required for calibration of the EDXA system. It is recommended that gold or nickel grids be used to facilitate detection of sodium. For calibration of the camera constant for interpretation of ED patterns, TEM specimen grids with vacuum-evaporated thin films of gold, aluminium or thallos [Tl(I)] chloride deposited on to carbon films are required.

9.2.5 Disposable tip micropipettes, suitable for transferring a volume of approximately 3 μ l to a carbon-coated TEM specimen grid.

9.3 Calibration

9.3.1 EDXA system

For the purposes of this method, calibration consists of obtaining EDXA spectra from reference samples of chrysotile, amosite, crocidolite, tremolite, actinolite, anthophyllite, and richterite/winchite. The chemical compositions of commercial chrysotile, amosite, crocidolite, and anthophyllite do not vary substantially, and comparison of unknown EDXA spectra with those from the three reference asbestos samples constitutes sufficient identification for this part 1 of ISO 22262. For most purposes, it is not necessary to discriminate between tremolite and actinolite, since the compositional boundary between them is a matter of convention. When it is necessary to discriminate between tremolite and actinolite, the SRM 1867 tremolite and actinolite samples are particularly useful since they have compositions just below and just above the boundary defined by the International Mineralogical Association (Reference [24]). In some applications, the magnesium may be partially leached from chrysotile, leading to a chemical composition that approaches that of talc. In order to facilitate the discrimination between chrysotile and talc or anthophyllite, it is recommended that an EDXA spectrum also be obtained from a known sample of talc. Use this spectrum to define the upper limit of the magnesium mass fraction in talc. Examples of EDXA spectra obtained on the SRM 1866 and SRM 1867 samples, the HSE reference asbestos samples, Bolivian crocidolite, and richterite/winchite appear in Annex F. For positive identification, reference EDXA spectra from asbestos standards similar to those shown in Annex F should be recorded using the specific combination of TEM and EDXA detector, since the geometries and detector efficiencies vary between different instruments.

9.3.2 Camera constant for interpretation of ED patterns

Use gold, aluminium or thallos [Tl(I)] chloride to calibrate the radius-based camera constant, λL , the product of the wavelength and camera length, for electron diffraction patterns. Specimen grids with a vacuum deposited, thin, polycrystalline film of one of these materials on a thin carbon film are used for the calibration. The calibration data for the first two diffraction rings, where D is the ring diameter, are shown in Table 6.

Table 6 — Radius-based camera constants

Calibration material	Radius-based camera constant λL	
	1st diffraction ring	2nd diffraction ring
Gold	0,117 74 <i>D</i>	0,101 97 <i>D</i>
Aluminium	0,116 90 <i>D</i>	0,101 24 <i>D</i>
Thallous [Tl(I)] chloride	0,192 14 <i>D</i>	0,135 86 <i>D</i>

9.4 Sample preparation

Remove representative fibres from the sample (see 7.2.2 and 7.2.3), and place them in an agate mortar, and pestle. Add approximately 1 ml of ethanol, and grind the fibres with the pestle until they are well dispersed in the ethanol. Set up a laboratory stand and clamp, and use it to hold a pair of fine-point tweezers that are supporting a carbon-coated TEM specimen grid, with the carbon side facing upwards. Using a disposable tip micropipette, drop a 3 μ l volume of the ethanol dispersion on to the grid, and allow it to dry. Drying is faster if the grid is held under a heat lamp. When dry, the TEM grid is ready for examination.

If crocidolite or sodic-calcic amphibole is suspected, use of a carbon-coated gold TEM grid is recommended in order to avoid partial overlap of the Na K_{α} peak by the Cu L_{α} X-ray peak if a copper grid is used.

9.5 Qualitative analysis by TEM

9.5.1 Acquisition of EDXA spectra

It is important to obtain the EDXA spectrum from clean areas of the fibre, since distortion of peak heights by contributions from attached particles may compromise the identification.

9.5.2 Chrysotile

The morphological structure of chrysotile as seen in the TEM is characteristic and, with experience, can be recognized readily. However, a few other minerals have a similar appearance, and morphological observation by itself is inadequate for most samples.

Classify a fibre as chrysotile if:

- the Mg and Si peaks are clear, and comparable in Mg/Si peak height ratio with that of reference chrysotile;
- any Fe, Mn and Al peaks are small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

IMPORTANT — Anthophyllite and talc both yield EDXA spectra that conform to these specifications, but the Mg/Si peak height ratio for these minerals is lower than that for chrysotile. In order to avoid erroneous classification of talc or anthophyllite as chrysotile, take account of the Mg/Si peak height ratio and calibrate the EDXA detector using known samples of chrysotile and talc.

9.5.3 Amosite

Classify a fibre as amosite if:

- the Mg, Si and Fe peaks are comparable in ratio to those of the reference amosite;
- no statistically significant peaks from Na or Al are present;
- the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

9.5.4 Crocidolite

Classify a fibre as crocidolite if:

- a) the Na, Si and Fe peaks are comparable in ratio with those of the reference crocidolite;
- b) no statistically significant peak from Al is present;
- c) any peak from Mg is small, and no Mn peak is visible.

NOTE 1 Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

NOTE 2 If a large peak from Mg is present, it is possible that the fibre is magnesio-riebeckite. Bolivian crocidolite is the only known commercial source, although this variety of crocidolite can occur as contamination of other minerals.

9.5.5 Tremolite

Classify a fibre as tremolite if:

- a) the Mg, Ca and Fe peaks are comparable in ratio with those of the reference tremolite;
- b) no statistically significant peak from Al is present;
- c) any peak from either Na or K is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

9.5.6 Actinolite

Classify a fibre as actinolite if:

- a) the Mg, Si and Fe peaks are comparable in ratio to those of the reference actinolite;
- b) no statistically significant peaks from Na or Al are present;
- c) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

9.5.7 Anthophyllite

Classify a fibre as anthophyllite if:

- a) the fibre is straight and exhibits no evidence of a ribbon-like structure;
- b) the Mg and Si peaks are comparable in ratio to those of reference anthophyllite — anthophyllite from some sources may not exhibit a peak from Fe, although in commercial anthophyllite a peak from Fe will probably be observed;
- c) no statistically significant peaks from Na or Al are present;
- d) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

9.5.8 Sodic–calcic amphibole asbestos (richterite/winchite)

Classify a fibre as sodic–calcic amphibole if:

- a) the spectrum is similar to that of actinolite or tremolite, but the Ca peak is substantially smaller and an Na peak is present — a K peak may also be evident;
- b) no statistically significant peak from Al is present;

- c) the Mn peak, if present, is small.

NOTE Depending on the composition of any adjacent or attached particles, other peaks can also be visible.

10 Test report

The test report shall contain at least the following information:

- a) reference to this part of ISO 22262 (ISO 22262-1:2012);
- b) the identification of the sample, including the location (if known by the analyst);
- c) the date of the analysis;
- d) the identity of the analyst;
- e) all applicable specimen preparation details;
- f) any procedure used not specified in this part of ISO 22262 or regarded as an optional procedure;
- g) the variety or varieties of asbestos detected;
- h) the analytical method used to identify the asbestos.

Items i) to k) shall be recorded in the laboratory data, but the extent to which they are included as part of the test report is optional:

- i) the observations made to confirm the identification of the asbestos varieties reported, including any optional procedures;
- j) the estimated mass fraction(s) of the asbestos varieties detected in ranges as follows:
 - 1) none detected,
 - 2) detected,
 - 3) 0,1 % to 5 %,
 - 4) 5 % to 50 %,
 - 5) 50 % to 100 %;

NOTE 1 These categories for reporting asbestos mass fractions are estimates only; they are intended to provide guidance in the interpretation of results. If it is necessary to make critical decisions on the basis of results in the range from "non-detected" to 5 %, sample analysis by a quantitative method is appropriate (e.g. using ISO 22262-2).

NOTE 2 The reporting category "detected" provides the analyst with a means of reporting the result when only one or two fibres are detected in the analysis, the observation of which may be a consequence of unintended contamination of the sample.

- k) the variety or varieties of any non-asbestos fibres detected, and the observations made which allowed these fibres to be discriminated from asbestos fibres.

An example of a suitable format for the test report is shown in Annex H.

Annex A (normative)

Types of commercial asbestos-containing material

The properties of asbestos such as non-flammability, chemical stability, and high strength have led worldwide to a broad use of this mineral in the building and industrial sectors. Asbestos–cement products, asbestos-containing lightweight panels and fire-prevention panels, asbestos packings and asbestos cloths, asbestos boards, asbestos foams, asbestos-containing fireproofing and acoustic and decorative plasters (sprayed asbestos), and asbestos-containing compositions for trowel application and putties are the most important uses. In addition, there is also a variety of products to which asbestos fibres were frequently added at smaller mass fractions, e.g. paints for protective coatings, adhesives, plastic sheets, and tiles.

Table A.1 gives the most important asbestos-containing materials with examples of their applications and the typical asbestos mass fractions. In exceptional cases, asbestos mass fractions deviating from those quoted may have been used.

Table A.1 — Asbestos-containing materials; examples of use and typical asbestos content

Product	Examples of application	Typical asbestos type and mass fraction
Asbestos–cement flat boards	Roof claddings Sidings Banister elements Windowsills Staircases Partition walls Support for cable runs In small sizes as slates and shingles in the roofing and siding sectors	Chrysotile 10 %–12 %, Sometimes also <5 % crocidolite or amosite in addition to chrysotile
Asbestos–cement corrugated sheets	Roof claddings Perimeter insulation Sidings in the industrial sector	Chrysotile 10 %–12 %, sometimes also, with some manufacturers, <5 % crocidolite in addition to chrysotile
Asbestos–cement pipes or ducts	Drinking water and wastewater pipes Service pipes Inlet air and exhaust air ducts Cable shafts	Chrysotile 10 %–15 %. Drinking water pipe also <5 % crocidolite or amosite in addition to chrysotile
Asbestos–cement mouldings	Standard ashtrays Flower boxes Garden articles Sculptures	Chrysotile 10 %–12 %

Table A.1 (continued)

Product	Examples of application	Typical asbestos type and mass fraction
Asbestos-containing lightweight building boards or fire-resistant panels	Sealing of openings in walls required to be fire resistant Fire-protection encasement of ventilation ducts, cable ducts and cable shafts Fire closures in walls required to be fire resistant (fire shutters, fire barriers) Fire-protection encasements Smoke-removal ducts Insert in fire-resistant doors and gates Substructure of luminaries (lighting fixtures)	Chrysotile ~15 % and amosite ~15 %
Asbestos-containing lightweight building boards or fire-resistant panels	Lining fire-hazard rooms Partition walls, partition surfaces, doors Sanitary modules Support and beam encasements Smoke aprons Fire locks	Chrysotile <50 %, sometimes amosite <35 %
Asbestos-containing pipe and boiler insulations	Corrugated paper pipe insulation 85 % magnesia block and pipe insulation Calcium silicate block and pipe insulation	Chrysotile 30 %–100 % Total of 15 % asbestos, can be chrysotile, amosite or crocidolite, or any mixture of two or more.
Asbestos packing, asbestos cloth	Seals or sealing strips on lightweight walls required to be fire resistant (at ceiling, floor, joints between elements, wall terminations) Seals on pipe and duct feed-throughs in walls and ceilings Seals between flanges of ventilation ducts Seals on fire-resistant glazing, shelter doors, chimney soot doors Seals and insulation on heat-generation systems, hot pipes and hot valves Fire blankets Heat-resistant clothing, heat-resistant gloves Lining of pipe clips for hot water, steam and sprinkler pipes Lamp wicks Mantles for gas lamps	Predominantly chrysotile (80 %–100 %); crocidolite for acid-resistant applications
Asbestos millboards	Sealing strips on lightweight walls required to be fire resistant (at ceiling, floor, joints between elements, wall terminations) Substructure of luminaries (lighting fixtures) Bottom coating of wooden windowsills over radiators	Chrysotile 80 %–100 %
Asbestos foams	Infilling (sealing) of movement joints Seals at fire shutters and fire barriers	Chrysotile ~50 %

Table A.1 (continued)

Product	Examples of application	Typical asbestos type and mass fraction
Sprayed asbestos	Contour-following fire-resistant coating of steel structures Coating of ceilings and walls in music auditoria, theatres, churches, garages, industrial rooms (for noise protection) Sealing off openings for cable, pipe and duct feed-throughs through walls required to be fire resistant Encasing of ventilation ducts	Chrysotile, crocidolite or amosite 40 %–70 %, also mixtures of mineral wool with either 20 % amosite or up to 30 % chrysotile. Other mixtures include 15 % chrysotile with either perlite or vermiculite, and gypsum. Sprayed vermiculite coatings (with or without chrysotile) can contain up to 2 % tremolite, some of which can be asbestiform. Several per cent of tremolite asbestos (Japan)
Sprayed decorative coatings (texture coats)	Coating of ceilings and walls to provide a textured surface which masks irregularities	Chrysotile <5 %. Some constituents can also contain tremolite. Some of the tremolite can be asbestiform.
Gypsum wallboard joint compounds	Provides smooth joint between adjacent panels	Chrysotile <5 %. Some constituents can also contain low mass fractions of tremolite.
Asbestos-containing troweled-on compositions and putty	Grouting of prefabricated concrete components Sealing of movement joints Pipe feeds through walls and ceilings Door casings of fire-resistant doors Anti-drumming coatings (car preservation) Coating of underwater structures Baseboard coating on house walls	Chrysotile <20 %
Asbestos-containing floorings	Reinforcement in flexible sheets Rot-resistant support layer as underlay of cushion PVC flooring materials	Chrysotile 10 %–20 % Chrysotile 80 %–100 %
Asphalt or PVC asbestos floor tiles	Reinforcement	Asphalt tiles containing chrysotile <35 %, PVC tiles containing chrysotile <20 %
Rubberized asbestos seals	Gaskets for pipe flanges	Chrysotile 50 %–90 %
Asbestos-containing friction products	Brake linings Brake bands Clutch linings	Chrysotile 10 %–70 %
Acid-resistant containers	Lead-acid battery boxes Drums for acid	Crocidolite 10 %–50 %
Filter media	Air filters Liquid filters Sterile and aseptic filters Clarifying sheets Diaphragms for chloralkali electrolysis processes Filtration media for Gooch crucibles	Chrysotile, rarely amosite 95 % For Gooch crucibles, 100 % tremolite or anthophyllite

Table A.1 (continued)

Product	Examples of application	Typical asbestos type and mass fraction
Talc (asbestos content dependent on deposit)	Release agents for electric cables, rubber products Release agents in the confectionery industry Tailor's chalk Paper manufacture Medicine, cosmetics	Chrysotile and/or actinolite/tremolite. Some of the actinolite/tremolite can be asbestiform
Vermiculite (exfoliated)	Attic and wall cavity insulation Fireproofing Horticultural products	Depends on the source of the vermiculite. Vermiculite from Montana, USA, can contain up to 6 % of a mixture of amphibole types, some of which can be asbestiform
Industrial minerals: wollastonite, sepiolite, attapulgite	Ceramics manufacture Plastics fillers Surfacing materials and joint compounds Ceiling tiles Drilling muds (attapulgite)	Depends on the source of the mineral. Can contain several per cent of tremolite or actinolite, some of which can be asbestiform.
Industrial minerals: calcite, dolomite and gypsum	Manufacture of building materials Industrial uses	Depends on the source of the mineral. Carbonate minerals can contain several per cent of tremolite or actinolite, some of which can be asbestiform
Industrial minerals: mica	Ceramics manufacture Manufacture of building materials	Depends on the source of the mineral. Can contain tremolite or actinolite, some of which can be asbestiform
Asphalt surfacings	Road construction	Chrysotile, generally ≤ 1 %
Wall and ceiling plasters	Interior wall and ceiling coatings, with or without aggregate and fibres such as animal hair or jute	Chrysotile. Generally locally mixed and inhomogeneous. Can be any mass fraction up to approximately 3 %
Drilling muds	Oil exploration, rock drilling	Chrysotile. Often the chrysotile is very fine and short, sometimes originating from Coalinga, California. Can contain <100 % chrysotile
Chemical products for construction, and other products	Bitumen, roofing and sealing sheets Sealing putties Glazing putties Bituminous coatings Fillers and sealers Jointing compounds Paints Glues Fire retardants Sub-floor protection	Chrysotile <30 % Chrysotile <2 % Chrysotile <4 % Chrysotile <30 % Chrysotile <25 % Chrysotile <5 % Chrysotile <9 % Chrysotile <4 % Chrysotile <10 % Chrysotile <4 %

Annex B (normative)

Interference colour chart

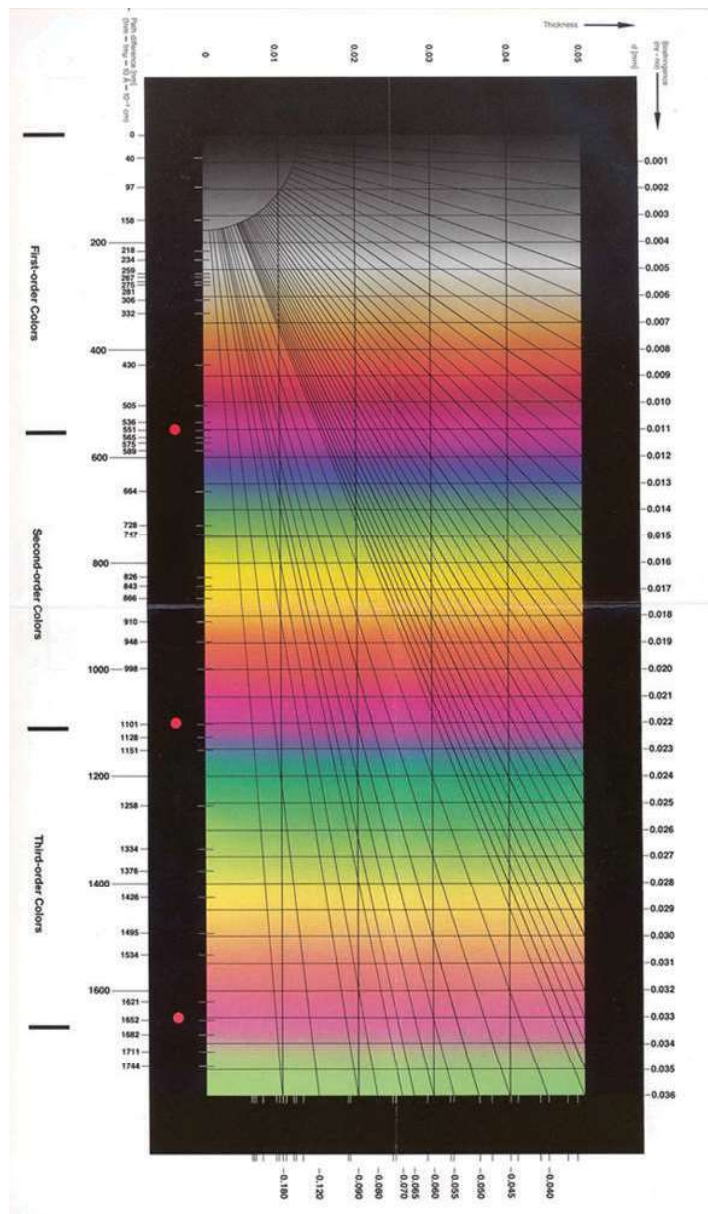


Figure B.1 — Interference colour chart

Annex C (normative)

Dispersion staining charts

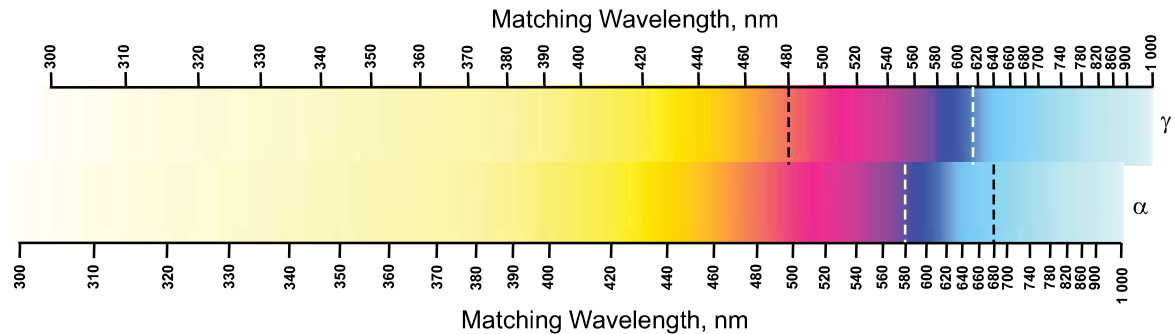


Figure C.1 — Central stop dispersion staining colours for chrysotile in 1,550 RI liquid

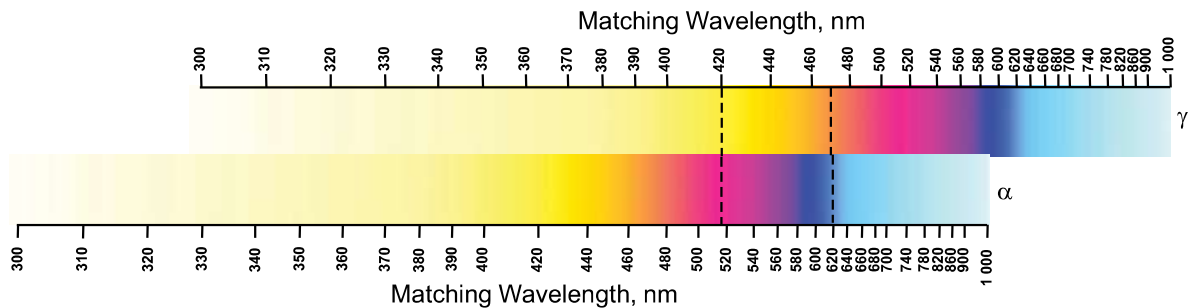


Figure C.2 — Central stop dispersion staining colours for amosite in 1,680 RI liquid

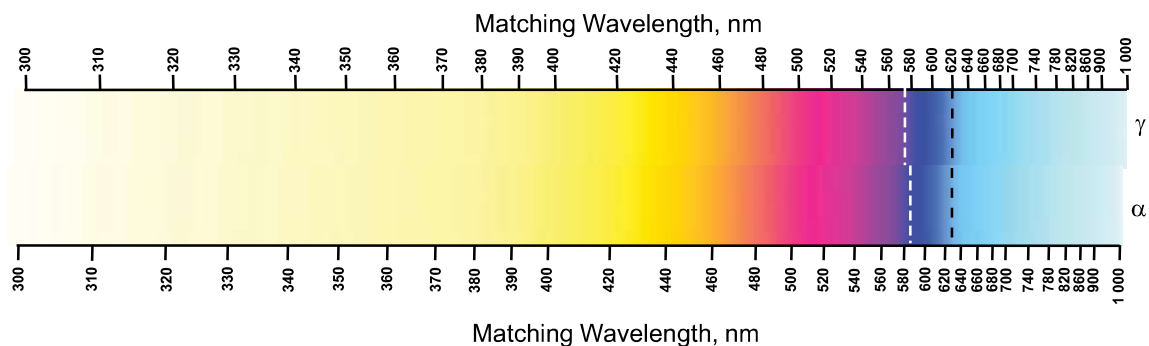


Figure C.3 — Central stop dispersion staining colours for crocidolite in 1,700 RI liquid

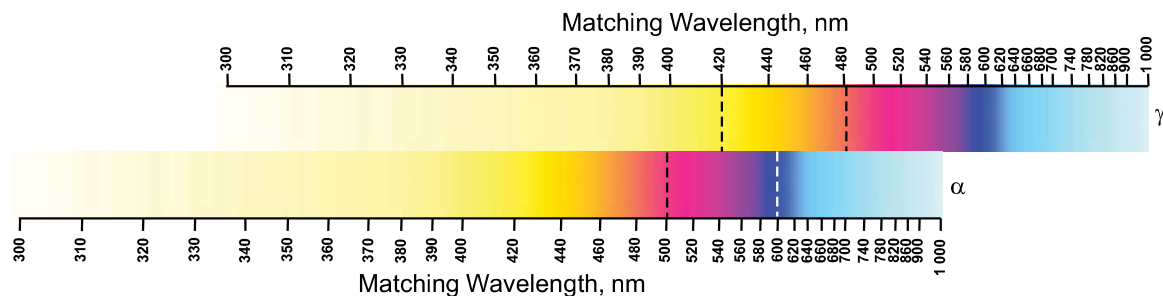


Figure C.4 — Central stop dispersion staining colours for tremolite in 1,605 RI liquid

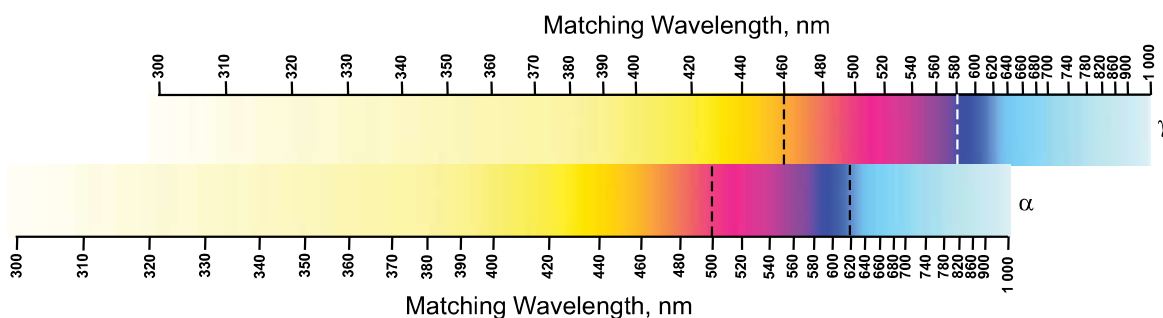


Figure C.5 — Central stop dispersion staining colours for actinolite in 1,630 RI liquid

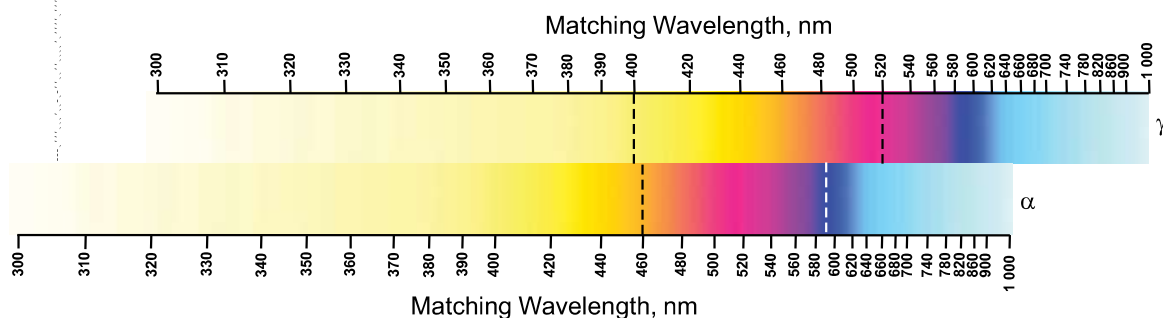


Figure C.6 — Central stop dispersion staining colours for anthophyllite in 1,605 RI liquid

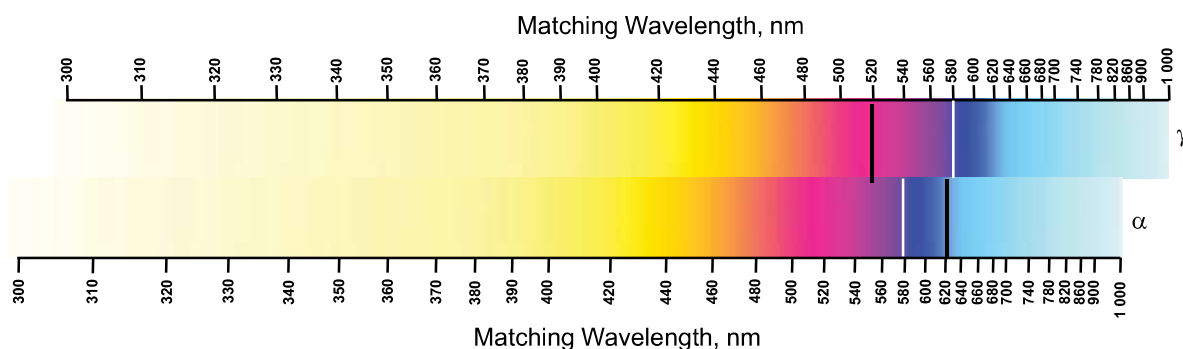


Figure C.7 — Central stop dispersion staining colours for richterite/winchite asbestos in 1,630 RI liquid

Annex D (normative)

Asbestos identification by PLM and dispersion staining in commercial materials

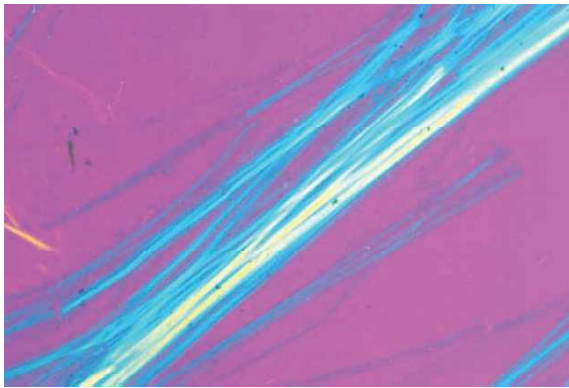


Figure D.1 — PLM micrograph of SRM 1866 chrysotile in 1,550 RI liquid — Crossed polars with 530 nm retardation plate

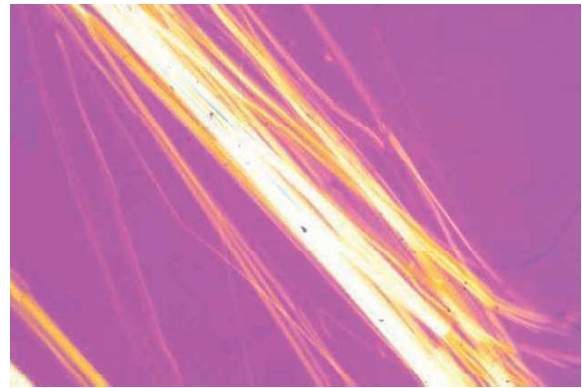


Figure D.2 — PLM micrograph of SRM 1866 chrysotile in 1,550 RI liquid — Crossed polars with 530 nm retardation plate

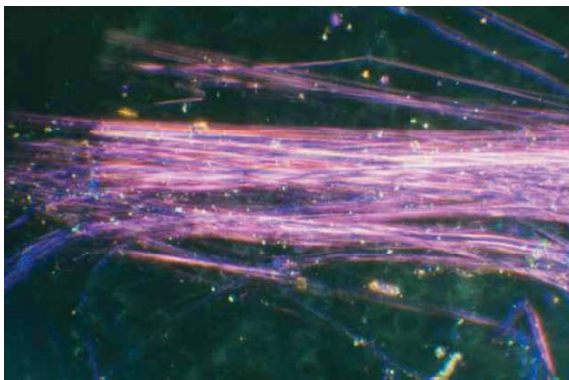


Figure D.3 — SRM 1866 chrysotile in 1,550 RI liquid viewed in dispersion staining — Fibre length parallel to polarizer vibration direction

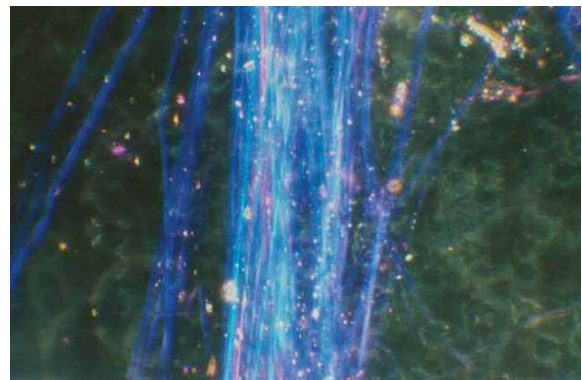


Figure D.4 — SRM 1866 chrysotile in 1,550 RI liquid viewed in dispersion staining — Fibre length normal to polarizer vibration direction

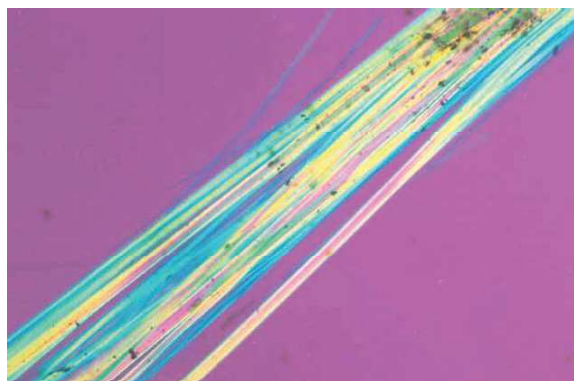


Figure D.5 — PLM micrograph of SRM 1866 amosite in 1,680 RI liquid — Crossed polars with 530 nm retardation plate

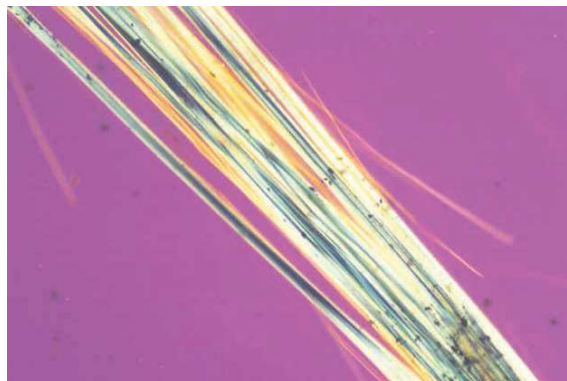


Figure D.6 — PLM micrograph of SRM 1866 amosite in 1,680 RI liquid — Crossed polars with 530 nm retardation plate

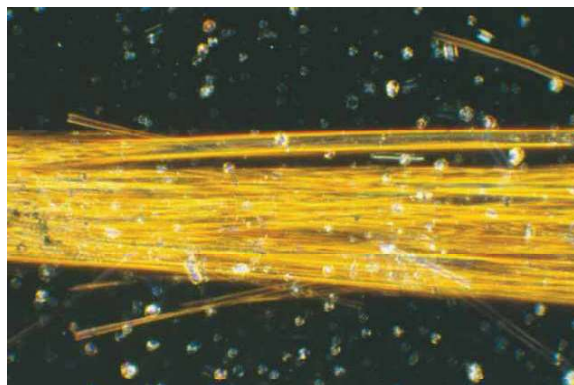


Figure D.7 — SRM 1866 amosite in 1,680 RI liquid viewed in dispersion staining — Fibre length parallel to polarizer vibration direction

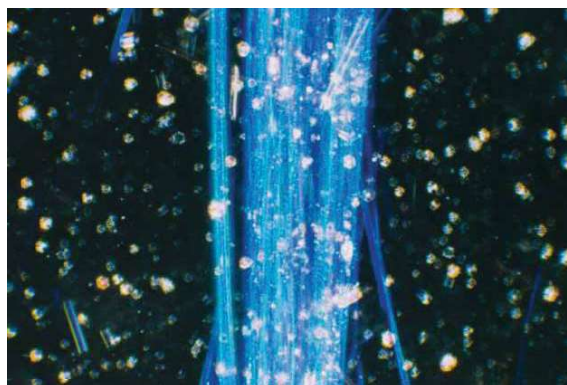


Figure D.8 — SRM 1866 amosite in 1,680 RI liquid viewed in dispersion staining — Fibre length normal to polarizer vibration direction



Figure D.9 — Heated amosite in 1,680 RI liquid viewed in plane polarized light — Fibre length parallel to polarizer vibration direction



Figure D.10 — Heated amosite in 1,680 RI liquid viewed in plane polarized light — Fibre length parallel to polarizer vibration direction

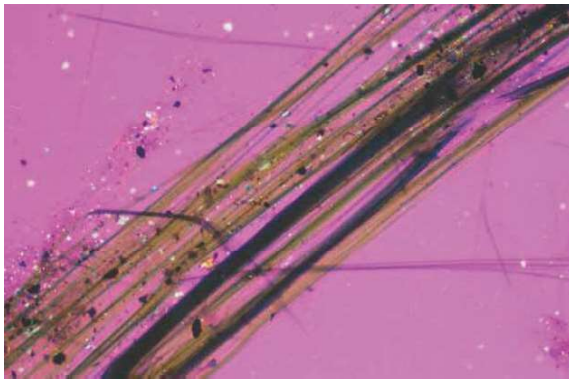


Figure D.11 — PLM micrograph of SRM 1866 crocidolite in 1,700 RI liquid — Crossed polars with 530 nm retardation plate

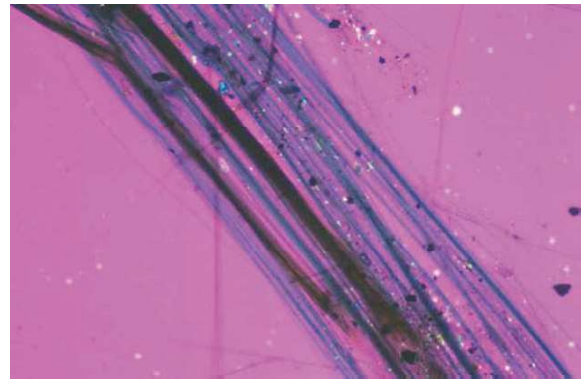


Figure D.12 — PLM micrograph of SRM 1866 crocidolite in 1,700 RI liquid — Crossed polars with 530 nm retardation plate

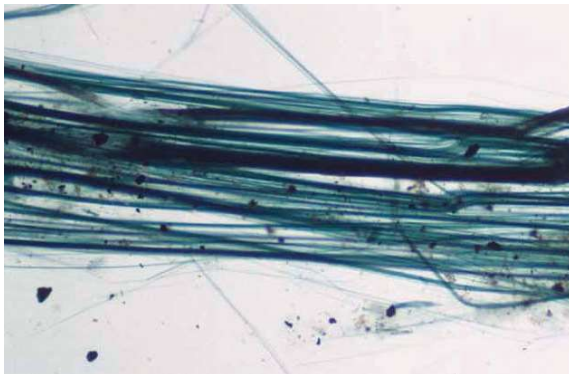


Figure D.13 — SRM 1866 crocidolite in 1,700 RI liquid in plane polarized light — Fibres parallel to polarizer vibration direction



Figure D.14 — SRM 1866 crocidolite in 1,700 RI liquid in plane polarized light — Fibres normal to polarizer vibration direction



Figure D.15 — SRM 1866 crocidolite in 1,700 RI liquid — Dispersion staining — Fibre lengths parallel to polarizer vibration direction



Figure D.16 — SRM 1866 crocidolite in 1,700 RI liquid — Dispersion staining — Fibre lengths normal to polarizer vibration direction



Figure D.17 — Heated crocidolite viewed in plane polarized light — Fibre length parallel to polarizer vibration direction



Figure D.18 — Heated crocidolite viewed in plane polarized light — Fibre length normal to polarizer vibration direction

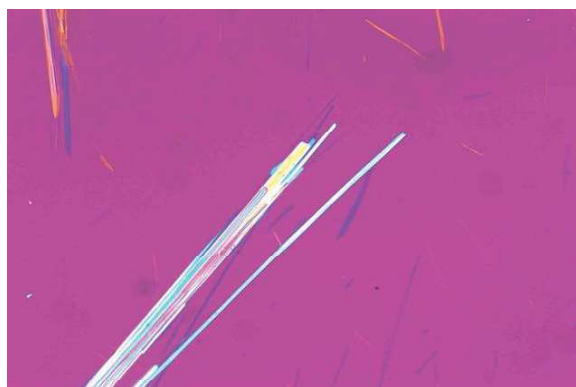


Figure D.19 — PLM micrograph of SRM 1867 tremolite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate

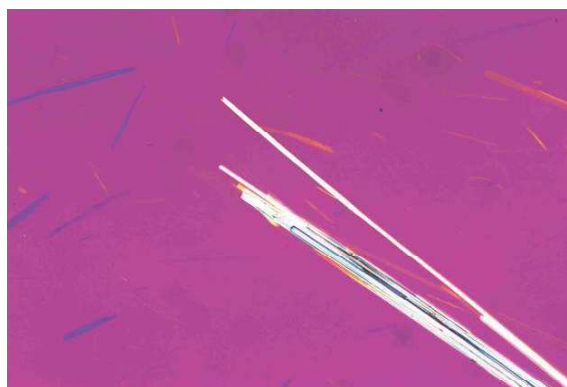


Figure D.20 — PLM micrograph of SRM 1867 tremolite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate

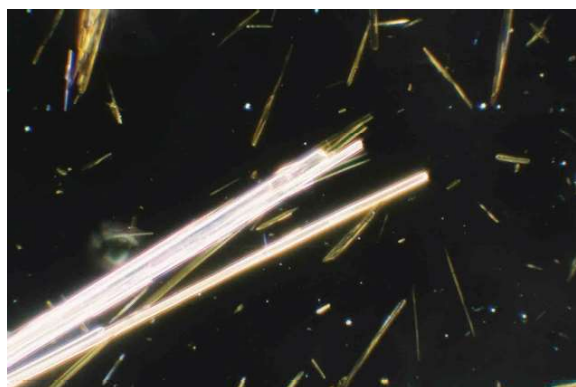


Figure D.21 — SRM 1867 tremolite in 1,605 RI liquid viewed in dispersion staining — Fibres at extinction position



Figure D.22 — SRM 1867 tremolite in 1,605 RI liquid viewed in dispersion staining — Fibres at extinction position

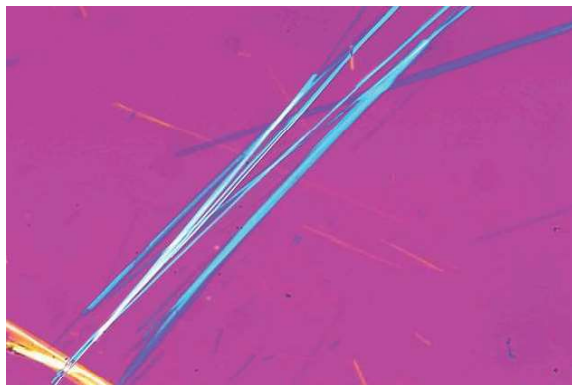


Figure D.23 — PLM micrograph of SRM 1867 tremolite in 1,625 RI liquid — Crossed polars with 530 nm retardation plate

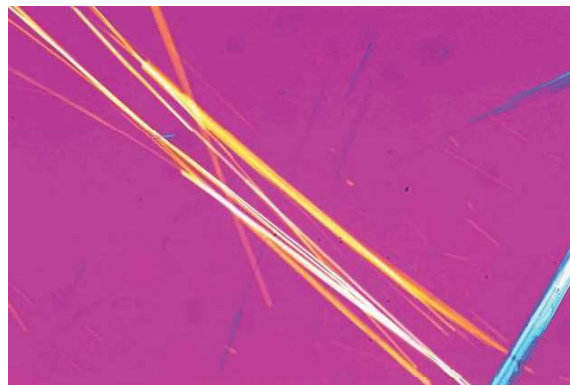


Figure D.24 — PLM micrograph of SRM 1867 tremolite in 1,625 RI liquid — Crossed polars with 530 nm retardation plate

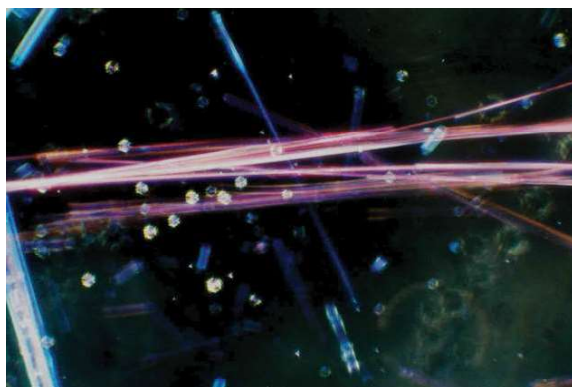


Figure D.25 — SRM 1867 tremolite in 1,625 RI liquid viewed in dispersion staining — Fibres at extinction position

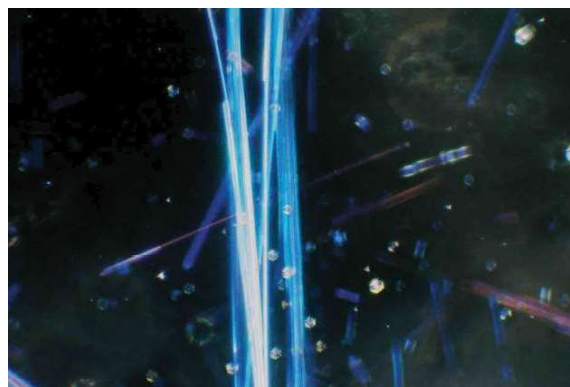


Figure D.26 — SRM 1867 tremolite in 1,625 RI liquid viewed in dispersion staining — Fibres at extinction position

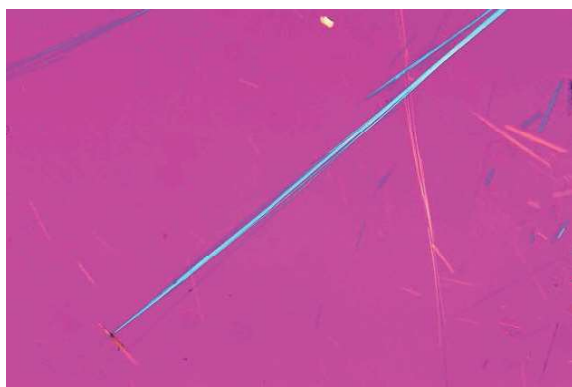


Figure D.27 — PLM micrograph of SRM 1867 actinolite in 1,630 RI liquid — Crossed polars with 530 nm retardation plate



Figure D.28 — PLM micrograph of SRM 1867 actinolite in 1,630 RI liquid — Crossed polars with 530 nm retardation plate

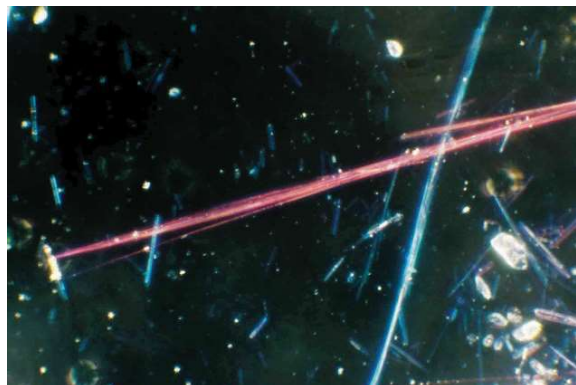


Figure D.29 — SRM 1867 actinolite in 1,630 RI liquid viewed in dispersion staining — Purple fibre at extinction position



Figure D.30 — SRM 1867 actinolite in 1,630 RI liquid viewed in dispersion staining — Light blue fibre at extinction position

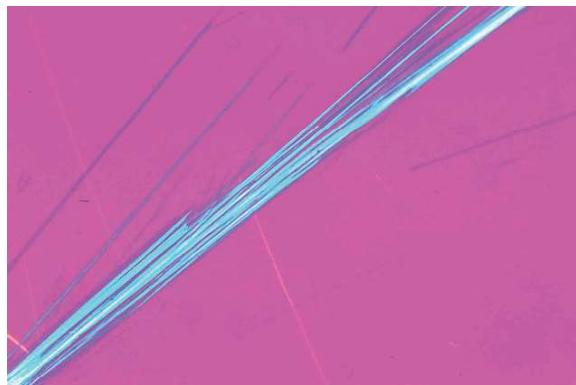


Figure D.31 — PLM micrograph of SRM 1867 anthophyllite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate

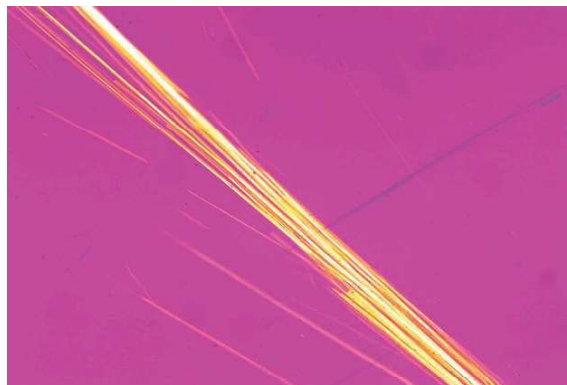


Figure D.32 — PLM micrograph of SRM 1867 anthophyllite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate

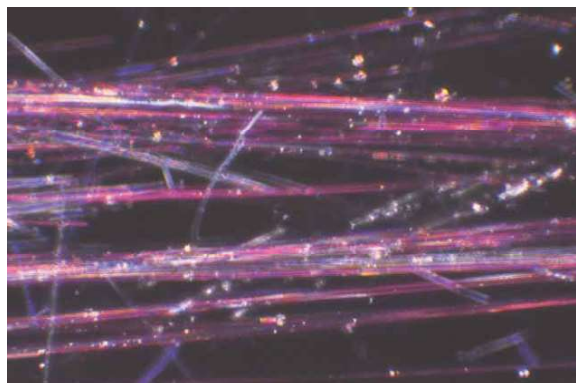


Figure D.33 — SRM 1867 anthophyllite in 1,630 RI liquid viewed in dispersion staining — Fibre lengths parallel to polarizer vibration direction

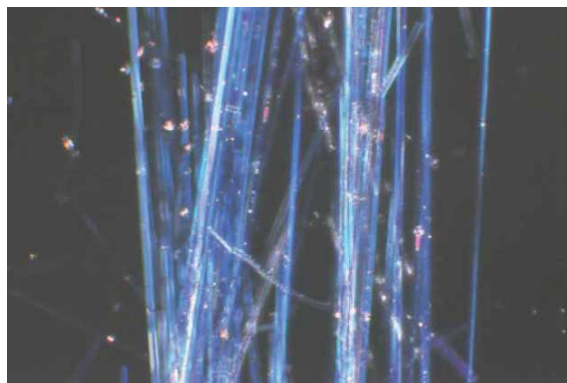


Figure D.34 — SRM 1867 anthophyllite in 1,630 RI liquid viewed in dispersion staining — Fibre lengths normal to polarizer vibration direction

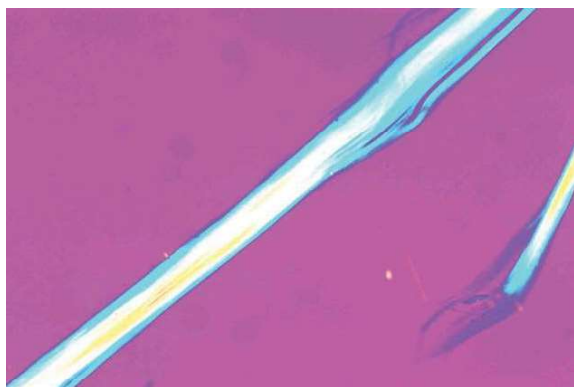


Figure D.35 — PLM micrograph of HSE tremolite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate

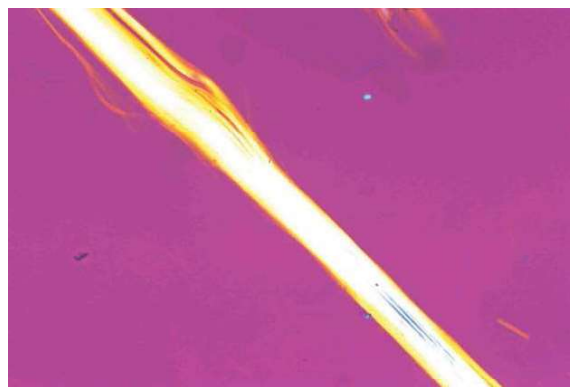


Figure D.36 — PLM micrograph of HSE tremolite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate



Figure D.37 — HSE tremolite in 1,605 RI liquid viewed in dispersion staining — Fibre lengths parallel to polarizer vibration direction

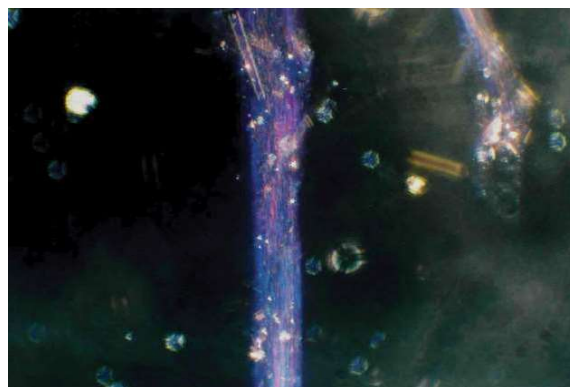


Figure D.38 — HSE tremolite in 1,605 RI liquid viewed in dispersion staining — Fibre lengths normal to polarizer vibration direction

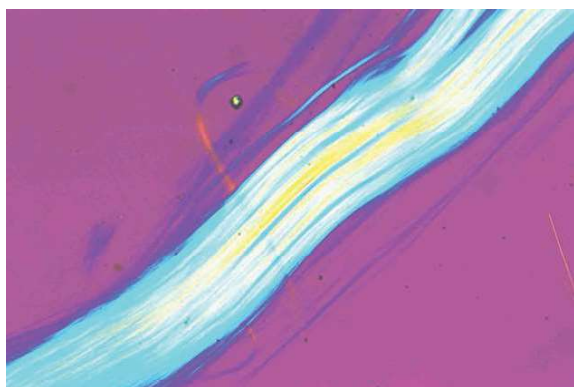


Figure D.39 — PLM micrograph of HSE actinolite in 1,640 RI liquid — Crossed polars with 530 nm retardation plate

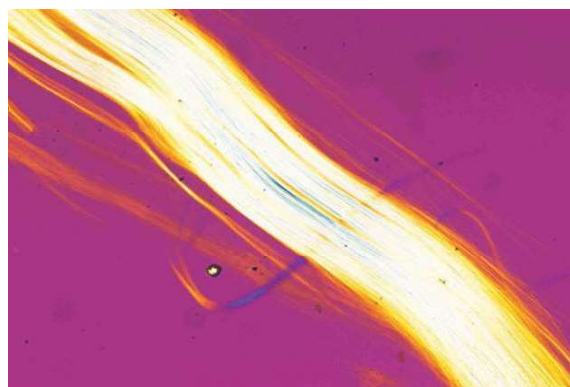


Figure D.40 — PLM micrograph of HSE actinolite in 1,640 RI liquid — Crossed polars with 530 nm retardation plate

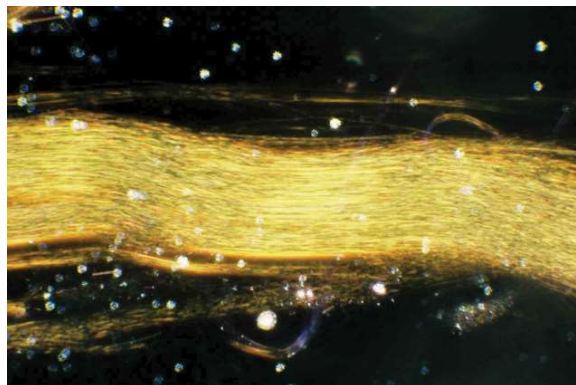


Figure D.41 — HSE actinolite in 1,640 RI liquid viewed in dispersion staining — Fibre lengths parallel to polarizer vibration direction



Figure D.42 — HSE actinolite in 1,640 RI liquid viewed in dispersion staining — Fibre lengths normal to polarizer vibration direction

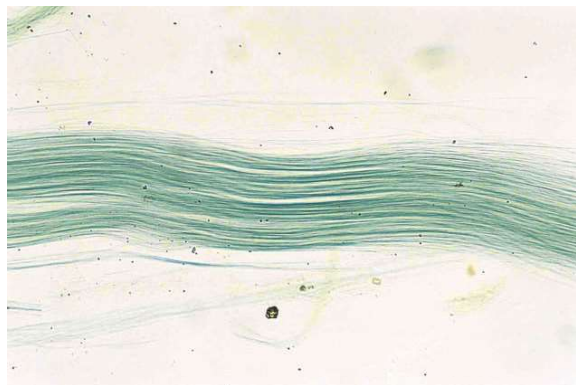


Figure D.43 — HSE actinolite in 1,640 RI liquid in plane polarized light — Fibres parallel to polarizer vibration direction



Figure D.44 — HSE actinolite in 1,640 RI liquid in plane polarized light — Fibres normal to polarizer vibration direction

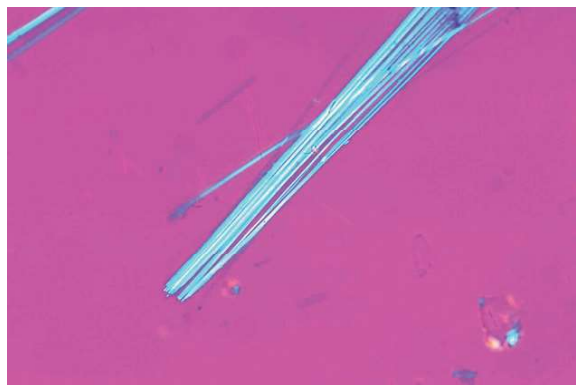


Figure D.45 — PLM micrograph of HSE anthophyllite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate

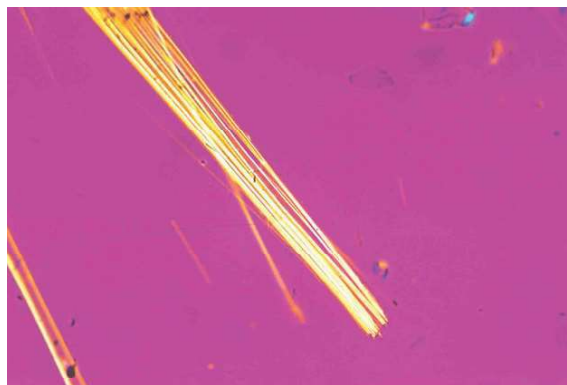


Figure D.46 — PLM micrograph of HSE anthophyllite in 1,605 RI liquid — Crossed polars with 530 nm retardation plate

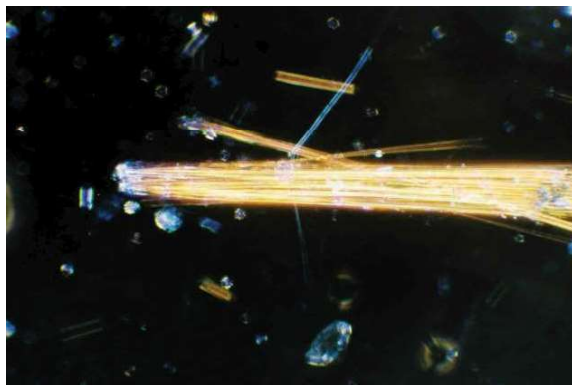


Figure D.47 — HSE anthophyllite in 1,605 RI liquid viewed in dispersion staining — Fibre lengths parallel to polarizer vibration direction

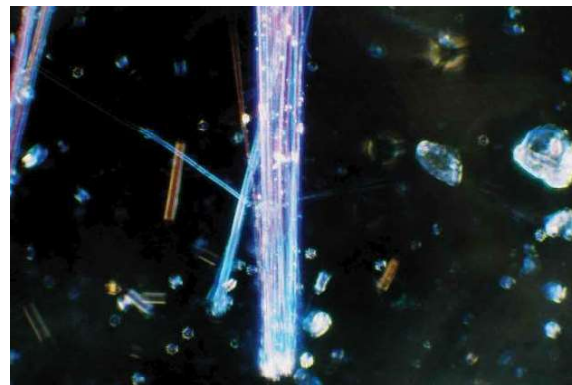


Figure D.48 — HSE anthophyllite in 1,605 RI liquid viewed in dispersion staining — Fibre lengths normal to polarizer vibration direction



Figure D.49 — PLM micrograph of richterite/winchite asbestos in 1,630 RI liquid — Crossed polars with 530 nm retardation plate

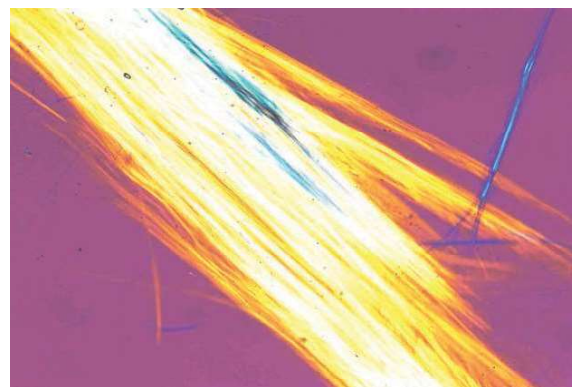


Figure D.50 — PLM micrograph of richterite/winchite asbestos in 1,630 RI liquid — Crossed polars with 530 nm retardation plate



Figure D.51 — Richterite/winchite asbestos in 1,630 RI liquid viewed in dispersion staining — Fibres at extinction position

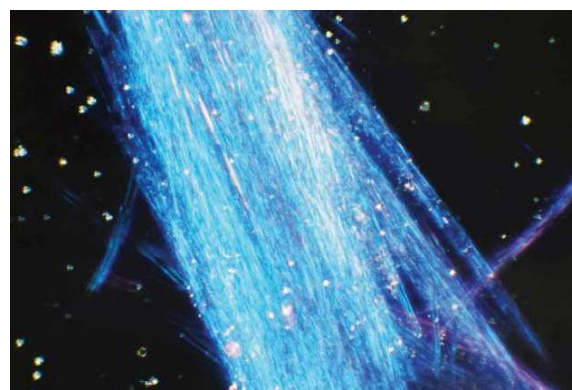


Figure D.52 — Richterite/winchite asbestos in 1,630 RI liquid viewed in dispersion staining — Fibres at extinction position